ASTR 288C – Research Project

Due: 7 **December 2009**

Value: **40% of Course Grade**

Light Curves of SN2008aw

Introduction

The purpose of this research project is to gain experience analyzing real astronomical data and presenting your work. You will work with ultraviolet and optical image data from the *Swift* satellite taken using the Ultraviolet/Optical Telescope (UVOT). The goal is to produce uvw1- and *v*-band light curves, and to combine the data to generate a uvw1−*v* colour curve. You will write a short paper describing what you did, and make a brief presentation during the final class on 7 December 2009.

SN2008aw

In 2005 *Swift* began a long-term campaign to observe supernova light curves. *Swift* has two unique properties that make it highly suited for supernova observations. First, *Swift* can respond rapidly when a new supernova is discovered. Target of Opportunity observations can begin within four hours of a supernova's discovery. This means that, if a supernova is discovered early enough, it is possible to follow the rise of the light curve to peak light. Second, *Swift* is above the Earth atmosphere, so it can observe at ultraviolet wavelengths. Ultraviolet light bluer than about 3000 Å is blocked by the Earth's atmosphere, so space-based observations are needed observe shorter wavelengths than this.

The supernova SN2008aw was discovered by Alex Filippenko of the University of California at Berkeley on 2 Mar 2008. It is a Type II supernova that reached a peak magnitude of $V \approx 16$. *Swift* observed SN2008aw for approximately three weeks in the Spring of 2008, and again several weeks later. This last observation was taken after the supernova had faded significantly. There were two goals for this late-time observation. First, the observer wanted to see if the supernova had faded to the point where UVOT could no longer detect it. Second, if the supernova was no longer detected, the goal was to determine the brightness and colour of the underlying host galaxy at the location of the supernova.

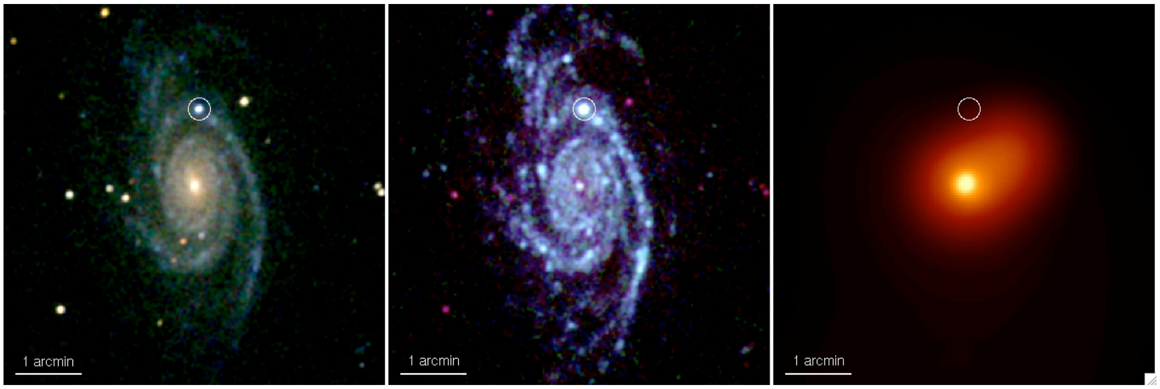

Figure 1. The left-hand image is a combined optical image of the host galaxy of SN2008aw constructed from UVOT *ubv* data. The middle image shows the host in the ultraviolet. It was constructed from UVOT uvw1, uvm2, and uvw2 exposures. The right-hand image is an *X*-ray image taken with *Swift*'s *X*-Ray Telescope. SN2008aw is indicated with a circle near the top of the galaxy. Note that the supernova is located in one of the galaxy's spiral arms. Also note that no *X*-ray signal is seen from this supernova. The host galaxy is NGC 4939, a Seyfert 2 spiral galaxy located approximately 44 Mpc away.

Some Useful Resources

- The *Swift* Science Centre
  http://swift.gsfc.nasa.gov/docs/swift/swiftsc.html
- The *Swift* Data Archive
  http://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/swift.pl
- The UVOT software documentation is available at
  http://swift.gsfc.nasa.gov/docs/swift/analysis/
- The *UVOT User's Guide* is available at
  http://swift.gsfc.nasa.gov/docs/swift/analysis/UVOT_swguide_v2_2.pdf
- The online FTOOLS help pages
  > fhelp *toolname*

Data

For this project you will use *Swift*/UVOT data. The data can be obtained from the *Swift* Data Archive at

http://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/swift.pl

Search for all of the data associated with SN2008aw. Note that most of the data was taken in March 2008, but some observations were taken later. Download the following UVOT files for each observation of SN2008aw.

- UVOT Image Level 2 files
  - sw*uw1_sk.img.gz
  - sw*uvv_sk_img.gz

The "*" will be a number that identifies the observation. The ".gz" indicates that the file is compressed. An example file name is "sw00031153001uvv_sk.img". You will be downloading thirteen UVOT SKY image files (those with an "_sk.img" at the end of their names). These are the science-quality SKY image files. They have been fully preprocessed and are ready for photometry.

Once the data have been downloaded (and untarred if you chose the tarfile download option) you need to uncompress it. The easiest way to do this is to use the `gunzip -r` command at the top of the directory structure that contains the *Swift* data. For example, if your data is in a directory called "sn2008aw" then uncompress all the data using these commands.

- `cd sn2008aw`
- `gunzip -r *`

Data Reduction and Analysis

The data that you downloaded from the *Swift* Data Archive have already been preprocessed to map bad pixels, remove mod8 noise, and transform the data into celestial coordinates (called SKY coordinates for UVOT data). You will use the SWIFTTOOLS software that is part of the FTOOLS package to work with your UVOT data. You can get help on any FTOOL by typing `fhelp` *`toolname`* at a unix command line prompt. Replace *`toolname`* with the name of the tool that you want to get help for. Also see the UVOT User's Guide for more information on running the UVOT-specific software.

Coadding the Data

The first step in working with the UVOT data is to combine all of the data taken during a single observation. In general *Swift* observations of a source are broken into short exposures of not more than about 2000 s. This is done because of orbital constraints that restrict the maximum amount of time that *Swift* can observe a target before it is blocked by the Earth's limb. Because of this each "_sk.img" file can contain several exposures that where taken within a few orbits of each other. The luminosity of a supernova usually varies fairly slowly compared to the length of time covered by a typical *Swift* observation. A typical decay rate for a Type II supernova is ≈0.01 mag/day. Therefore, the expected change in the supernova's magnitude is small over the duration of an observation, so it is safe to add together all of the data from a single observation. *This is not always the case.* In general one should check that this is true before coadding data.

Use the UVOTIMSUM task to coadd the individual exposures in a single SKY file into a single image. Do this for all the data. You should end up with a single uvw1 and a single uvw2 image for each observation (13 coadded images in all, one for each SKY file). For example, to coadd all of the data in the file "sw00031153001uvv_sk.img" use the following command.

- `uvotimsum sw00031153001uvv_sk.img sw00031153001uvv_sum.img`

This command creates a single summed image and stores it in the file called "sw00031153001uvv_sum.img". Do this for every SKY file. There is no need to change any of the hidden parameters for this task, although you should read about what they do in the help file.

You should examine every coadded image with DS9 to ensure that nothing went wrong.

Photometry

Once you have all of your coadded images you need to perform photometry on the supernova using the method described in the UVOT Users Guide. Since we are interested in a single source in each image (the supernova) the best tool to use is UVOTSOURCE. To do photometry you first need to know the coordinates of the supernova. You can get the coordinates for SN2008aw from on-line catalogues such as NED. The UVOT SKY images (and the coadded images) have had a World Coordinate System applied to them, so tools like DS9 can return the coordinates of a source directly. When you have found SN2008aw you will need to set up two region files that will be used by UVOTSOURCE.

- Source Region File
  This file contains the coordinates of the supernova. Its format is
  `fk5;circle(RA,Dec,Radius")`
  The double quote (") after the radius parameter is ***required***. It indicates that the radius is specified in units of arcseconds. Pick a radius that is large enough to include most of the light from the supernova but small enough to minimize contamination from the sky and the host galaxy. See http://swift.gsfc.nasa.gov/docs/swift/analysis/threads/uvot_thread_aperture.html and http://swift.gsfc.nasa.gov/docs/swift/analysis/uvot_digest.html/apercor.html for a discussion of the UVOT source aperture. The size of the source aperture is very important.
- Background Region File
  This file contains the coordinates of a location in the image that has the same background properties as the source does. It has the same format as the source region file does,
  `fk5;circle(RA,Dec,Radius")`
  The choice of a background region is critical to getting high-precision photometry. It needs to be large enough to get a reliable estimate of the background that is not biased by small-number statistics. It also needs to be chosen so that the background is as similar as possible to the background where the supernova is.

Use DS9 to help you pick your source and background regions. Once the region files have been chosen run UVOTSOURCE on each coadded image to get magnitudes and errors for the supernova. Here is an example of running UVOTSOURCE on the file "sw00031153001uvv_sum.img".

```
> uvotsource sw00031153001uvv_sum.img src.reg bkg.reg N sw00031153001uvv_sum.cat
```

This creates a FITS file called "sw00031153001uvv_sum.cat" that contains the magnitude and other information about the source that was specified in the source region file "src.reg". Some critical information, such as the magnitude, is also printed to the screen. The value of *N* on the command line is the *N* in the *N*-sigma detection threshold. If the source is detected at more than the *N*-sigma significance level then a magnitude will be returned. If the source is detected at less than the *N*-sigma significance level then an upper limit to the magnitude will be returned.

You will need to think about whether or not you want to change any of the hidden parameters to UVOTSOURCE. The parameters for UVOTSOURCE are

```
image = sw00130088000uw2_sum.img+1      Input image file and extension
srcreg = src.reg                        Source region file
bkgreg = bkg.reg                        Background region file
sigma = 3                               Background threshold
(zerofile = CALDB)                      Zero points file
(coinfile = CALDB)                      Coincidence loss correction file
(psffile = CALDB)                       PSF calibration file
(lssfile = NONE)                        LSS calibration file
(expfile = NONE)                        Exposure map file
(syserr = no)                           Include systematic errors?
(frametime = DEFAULT)                   Frame time or DEFAULT [s]
(apercorr = CURVEOFGROWTH)              Aperture correction method
(fwhmsig = -1)                          uvotapercorr fwhmsig value
(deadtimecorr = yes)                    Already dead time corrected?
(output = ALL)                          Output type(s)
outfile = ./uvsrc_tmp.fits              FITS table of values
(centroid = no)                         Perform centroiding?
(cleanup = YES)                         Remove temporary files?
(clobber = NO)                          Remove pre-existing output files?
(chatter = 1)                           Verbosity level
(mode = ql)
```

Hidden parameters are shown in parenthesis. In general the hidden parameters should not be changed. However, there are a few exceptions that you may wish to change. You should think carefully about the values of the following parameters.

- lssfile
  If you set lssfile=CALDB then the software will try to correct for changes in the sensitivity across the detector. This is a small affect and is optional in this lab. Sensitivity variations are currently not well understood for the UVOT detector. They are very small near the centre of the detector and get larger towards the edges of the detector.
- syserr
  This determines if the systematic error in the calibration is to be added (in quadrature) to the statistical error in the magnitude. The systematic error is the same, and in the same direction for every data point. This is unlike the

statistical error, which is different for every data point. Therefore, the effect of the systematic error is to shift the entire light curve up or down by an amount consistent with the systematic error. Each data point is shifted by the same amount. Therefore, one does not want to add the systematic error to the errors in each data point. Set syserr=NO.

- apercorr
  This is a critical hidden parameter. If you use a circular source region with a radius of 5 arcsec or larger then use apercorr=NONE. If you use a circular source region with a radius of less than 5 arcsec then use apercorr=CURVEOFGROWTH. See http://swift.gsfc.nasa.gov/docs/swift/analysis/uvot_digest.html/apercor.html and the help file for UVOTSOURCE for more information about this.
- fwhmsig
  This is the uncertainty in the shape of a point source (such as a star). At present the UVOT Team recommends using a value of 15% (fwhmsig=15). Using the special value (fwhmsig=−1) will set the value of fwhmsig automatically. This is not recommended.
- centroid
  This controls whether or not the software will try to recompute the coordinates of the source. For this lab set centroid=NO because small-scale variations in the background light from the host galaxy can cause the recomputed position to be incorrect. We will assume that the position of the supernova is already known to high accuracy.

Please read the help file and the documentation for UVOTSOURCE for more details.

Data Analysis

When you have completed your photometry use it to construct two light curves, one for the uvw1-band data and one for the *v*-band data. A light curve is a plot with time on the X axis and magnitude, with error bars, on the Y axis. Both light curves should be plotted using the same vertical and horizontal scales. Next, compute the uvw1−*v* colour for each observation and use this to construct a colour curve for SN2008aw. Do not forget to compute the errors and show error bars.

Presenting Your Results

The Paper

Write a short (approximately one to three pages) paper describing what you did and what your results are. The paper should have the following sections.

- Title and Author
- Abstract
  Write a short paragraph that summarizes your work.
- Introduction
  Give a brief description of the project, *Swift*, and what you hope to learn.
- Data Analysis

Describe the data and what you did with it. Explain why you chose the values for the various software parameters that you used.

- Results

  Show your plots (the two light curves and the one colour curve) and answer the following questions

  1. What is the estimated peak magnitude in each filter?
  2. Do the peaks occur at the same time in each filter?
  3. Are the changes in colour (if any) statistically significant?
  4. Are there any factors that could be biasing your photometry?

  Discuss anything else that you think is interesting or important about your results.

- Conclusion

  Write a brief concluding paragraph.

- References

  List any papers or major documentation that you refer to in the paper.

Format the paper using LaTeX and hand in a printed copy in the class on 7 December, 2009. The paper does not need to be long, and there is no required length; however, it should be long enough to include the information listed above.

The Presentation

Prepare a brief presentation showing the key points of your work. Your presentation should be no more than two or three slides long. Concentrate on presenting a single key result, and *do not try to discuss everything that you did*. You will make this presentation in class on 7 December 2009. Your presentation must not be more than five minutes long. There will be a short question period after each presentation.

Your presentation can be done in PowerPoint, Word, or using other presentation software. However, please send an e-mail to Stephen.T.Holland@nasa.gov saying what format you want to use *before* starting your presentation. That way I can be sure that it is possible to display your presentation in class. One way to ensure that your presentation will work is to prepare it using whatever software you wish, but save it as a PDF file, and use the PDF file to make your presentation. Bring your presentation to class on a CD or a memory stick, or (better yet) e-mail a copy to me at least 24 hours before the class.